# INVERSIONS OVER THE TROPICAL EASTERN PACIFIC OCEAN [1]

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ABSTRACT

Two definite levels of subsidence inversions were found over the tropical Eastern Pacific Ocean during the winter of 1964; both were mainly persistent and continuous. The existence of the lower inversion has been known, but that of the upper inversion at a mean height of 550 mb. has not. It is hypothesized that the upper inversion is caused and maintained by the subsidence in the warm "dynamic" anticyclone centered over Central America during winter. Both inversions appear to act as "lids" on cloud height development.

## 1. INTRODUCTION

The basic material used in this study is the data gathered during the period January 12 through March 18, 1964, by the meteorological group, headed by Dr. C. E. Palmer. The group was a small part of the "Galapagos International Scientific Project" comprised of many other members of the scientific community. The research ship *Golden Bear* sailed from San Diego to Galapagos Islands, Peru, Tahiti, Galapagos Islands, Ecuador, Cocos Island, and returned to San Diego. Darwin Research Station was set up at Academy Bay, Santa Cruz, Galapagos Islands for the period January 24 through February 24, 1964. (See fig. 1.) Surface weather observations were taken every 6 hr. and radiosonde observations were taken at least once a day on the *Golden Bear* and at Darwin Research Station.

## 2. RADISONDE SOUNDINGS

Sometimes inversions may be present in cases where radiosonde soundings do not show them, and vice versa, due to instrumental and other errors. The main sources of errors are given in [5]. For temperature, it concludes that a standard deviation error of $\pm 1.0$°C. may be expected. But, it notes that the errors are mostly systematic so that studies of the variation of lapse rate of temperature will not be greatly affected by these errors. For humidity measurements, Wexler [6] found a standard deviation error of $\pm 5.2$ percent relative humidity at $-20$°C. and 50 percent relative humidity. He also reported that when an inversion is penetrated by the radiosonde instrument, the reported humidity element lags behind the decreasing humidity of the atmosphere. Danielsen [1] found that variations in the lapse rate of individual soundings were related in space and time.

## 3. SUBSIDENCE INVERSION

A subsidence inversion is one which has been produced by a general sinking of air over a large area and a characteristic feature of this type of inversion is the decrease of moisture upward through the layer. Namias [2] showed that in the great majority of cases in the atmosphere, subsidence is closely connected with the horizontal divergence within the atmosphere. He explained that the constancy of potential temperature along the surface of subsidence exists because the surfaces of constant potential temperature are approximately horizontal in the source region and therefore, the evenly distributed adiabatic sinking of a layer will lead to a downfall displacement of the surface of constant potential temperature. Divergence (and convergence) above and below the inversion layer, radiation, and turbulence will vary the potential temperature along the surface of the inversion. Neiburger et al. [3] reported on the characteristics of the subtropical inversion of the eastern North Pacific, the westward upslope and diurnal variation of the height of the inversion off the California coast. All of the cases studied were for the Northern Hemisphere summer months. They found that even if their data could not be reduced to a common time, in spite of the time difference, a reasonable and useful product was arrived at when the data were used as if they occurred at a common time.

## 4. LOWER AND UPPER INVERSIONS

Detailed soundings were taken on the *Golden Bear* and *USS Pine Island* and at Darwin Research Station. These soundings, with those of Canton Island and Albrook AFB, Panama, were plotted on AWS Skew-T diagrams and analyzed. For this study, if the decrease of temperature in a layer (between significant levels) was less than 0.3°C., this layer was considered an inversion if there was constancy of potential temperature in time and space. These

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[1] This research was part of the author's Masters thesis written in the Atmospheric Research Laboratory, Institute of Geophysics, University of California at Los Angeles, which was supported by the National Science Foundation under grant GP/2414.

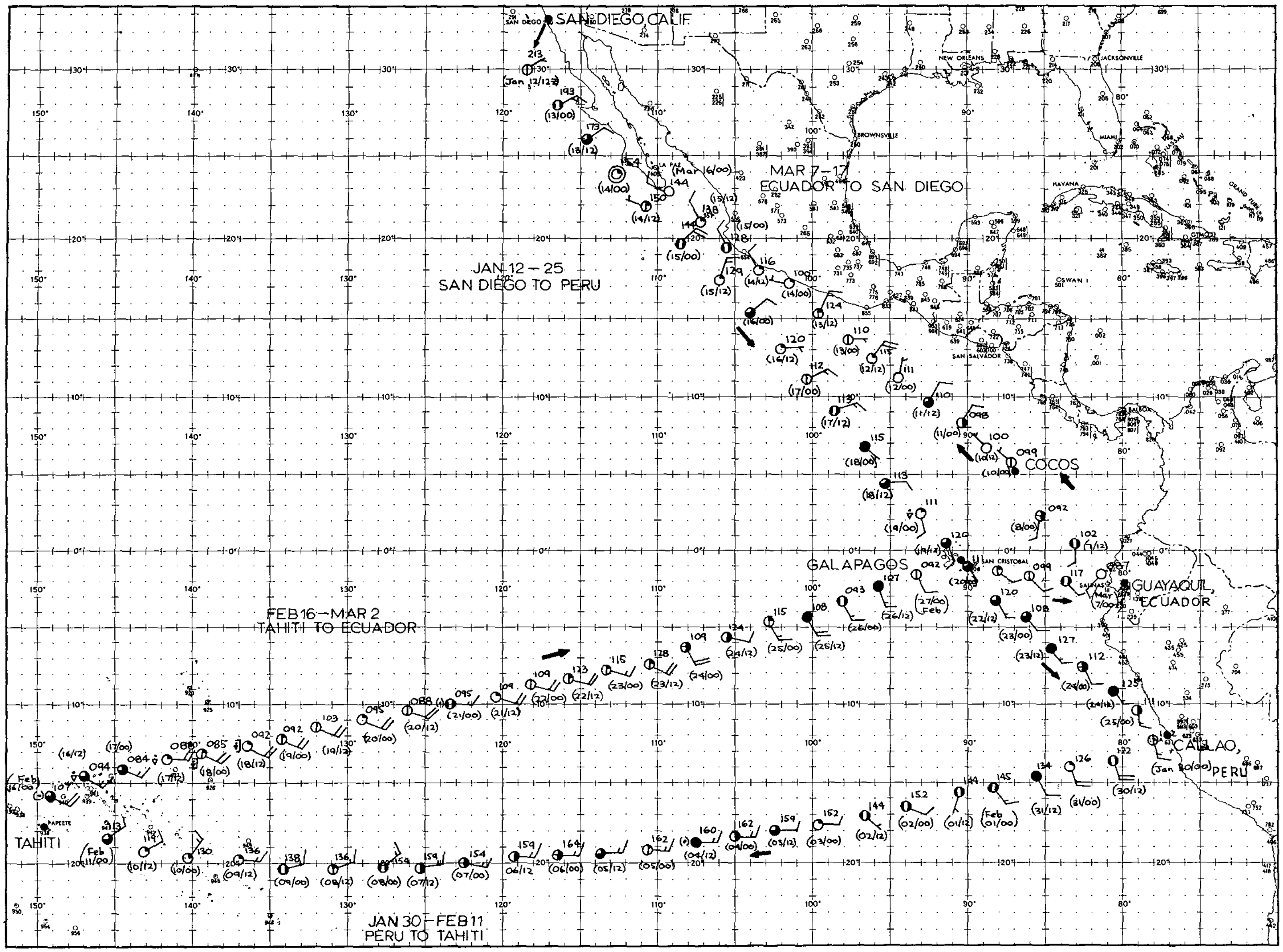


FIGURE 1.—Surface observations taken on the cruise of the *Golden Bear* during the period January 12–March 17, 1964.

few stable layers were noted with dashes in the figures that will present the inversions. In the calculation for the increase of temperature ($\Delta T$) in the inversion layer, these stable layers with a minus numerical value were considered isothermal. In the few cases of double inversions, the increase of temperature in the inversion layer was taken as the average of the double inversions' increase in temperature. The pressure at the base of the inversion will be referred to as the height of the inversion. Most of the inversions occurred in two basic layers: the lower one between 999 mb. and 725 mb. and the upper between 600 mb. and 400 mb. Figure 2 is an example of a sounding taken at Darwin Research Station depicting the lower and upper inversions. Other minor stable layers which were not persistent are also seen. The numbers on the right hand side of the points along the temperature line are relative humidity values.

Figures 3–5 and figure 7 are graphs showing the inversions along the legs of the cruise of the *Golden Bear*. The position of the ship, weather, and time of observation are given in the rows along the base of the graphs. Figure 8 shows the time variations of the inversions at Darwin Research Station and the *USS Pine Island*. The dots in the graphs represent the base and top limits of the inversions.

### CRUISE OF THE *GOLDEN BEAR*, SAN DIEGO TO PERU VIA GALAPAGOS ISLANDS, JANUARY 12–25, 1964

The lower inversion was present in practically all soundings during the cruise from San Diego to Peru (fig. 3). Close to the Mexican coast, the height of the inversion was quite uniform and averaged 877 mb., but south of 13°N. latitude, it was higher to near the coast of Peru. The low height of the inversion in the north was probably due to the effect of divergence of the air above and the cold sea. It is seen that the inversion was highest from 7°N. to the Equator. The surface streamline analyses for this period showed that the Intertropical Convergence Zone (ITC) was oriented east to west along 5°N. latitude. Off the Peruvian coast, where the inversion was

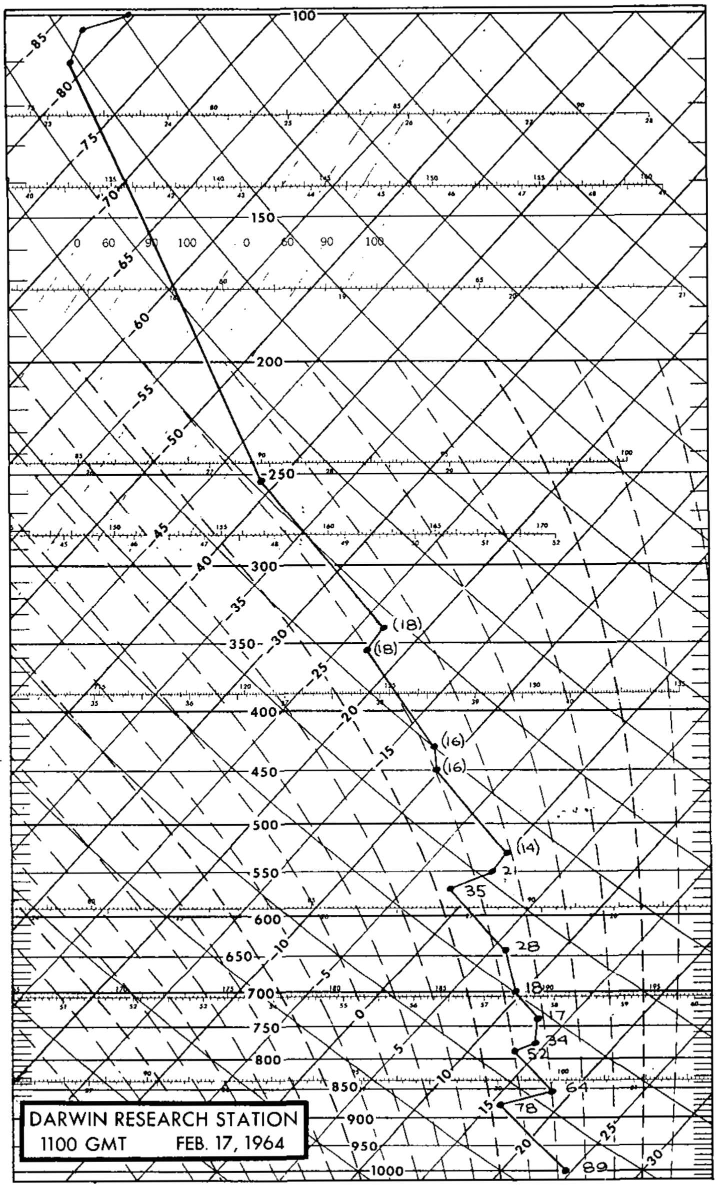


Figure 2.—Plotted sounding taken at Darwin Research Station at 1100 GMT, February 17, 1964, showing the lower and upper inversions.

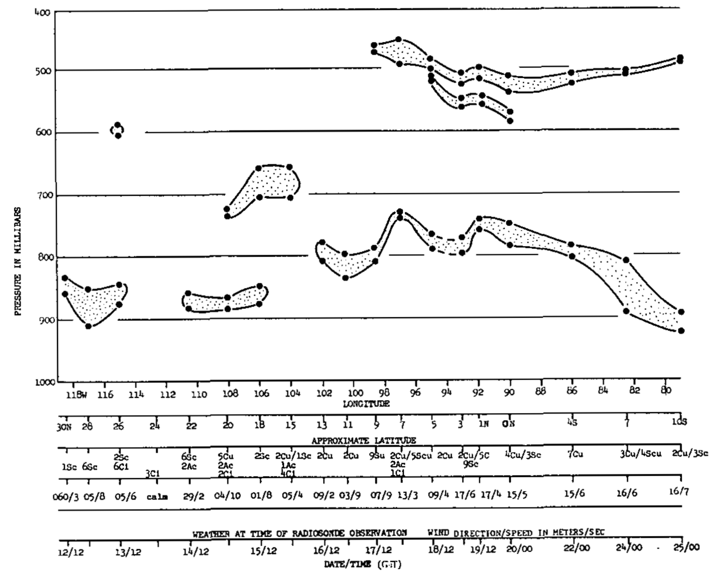


FIGURE 3.—Inversions occurring during the cruise of the *Golden Bear*, San Diego to Peru leg, January 12–25, 1964.

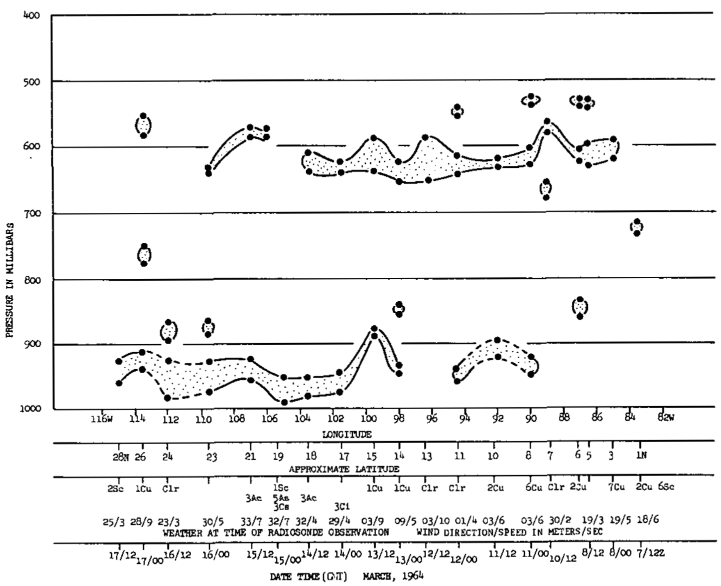


FIGURE 4.—Inversions occurring during the cruise of the *Golden Bear*, Ecuador-San Diego leg, March 7-17, 1964.

again over cold water, it descended to its lowest position. The average potential temperature of the inversion's base and top south of 13°N. was 10°C. higher than that to the north. This indicates that the air over the two areas originated from different sources. The subsiding air over the northern segment originated from the North Pacific and experienced a strong divergence above the cold sea water to create the low inversion and the air reaching the second came from the Caribbean Sea. The upper inversion was not present in the soundings north of 9°N., 99°W.; from there it was continuous the remaining way to Peru.

## CRUISE OF THE *GOLDEN BEAR*, ECUADOR TO SAN DIEGO VIA COCOS ISLAND, MARCH 7–17, 1964

During the cruise from Ecuador to San Diego (fig. 4), the lower inversion did not appear southeast of 8°N., 90°W., which is the region of the ITC. Then it was lifted slightly by heating from below over the warmer water to 15°N. but the rise in height was not appreciable indicating that the divergence of the air above was the more important factor in establishing the height of the inversion. The upper inversion was continuous from 3°N., 85°W., to 18°N., 104°W.

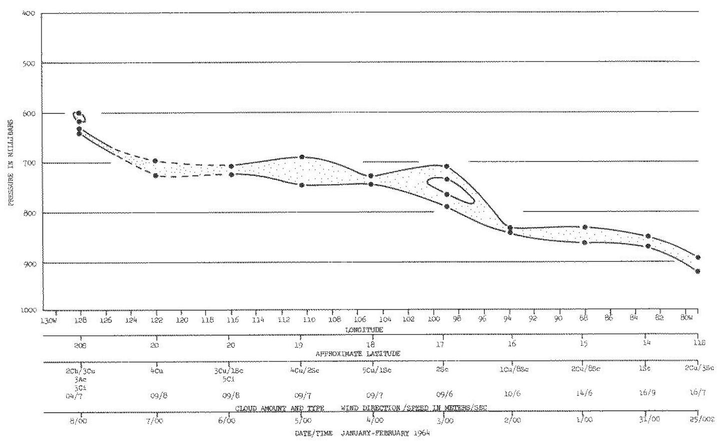


FIGURE 5.—Inversions occurring during the cruise of the *Golden Bear*, Peru to Tahiti leg, January 31–February 11, 1964.

### CRUISE OF THE *GOLDEN BEAR*, PERU TO TAHITI, JANUARY 31–FEBRUARY 11, 1964

During the cruise from Peru to Tahiti (fig. 5), the lower inversion rose rapidly just off the coast and then slowly westward to 16°S., 94°W., where it rose abruptly to 17°S., 99°W. From this point on, the inversion rose gradually to 20°S., 122°W., where it rose rapidly and vanished. The low height of the inversion extending westward over 1,000 mi. from the coast was caused in part by the cold water of the Southern Equatorial Current flowing westward from the coast. Figure 6 shows the cold current. The average increase in temperature ($\Delta T$) through the inversion over this cold tongue was 10.2°C. which was the sharpest inversion encountered on the entire cruise. The last three soundings taken near Tahiti did not record any inversion because of a nearby tropical cyclone. No upper inversion was observed.

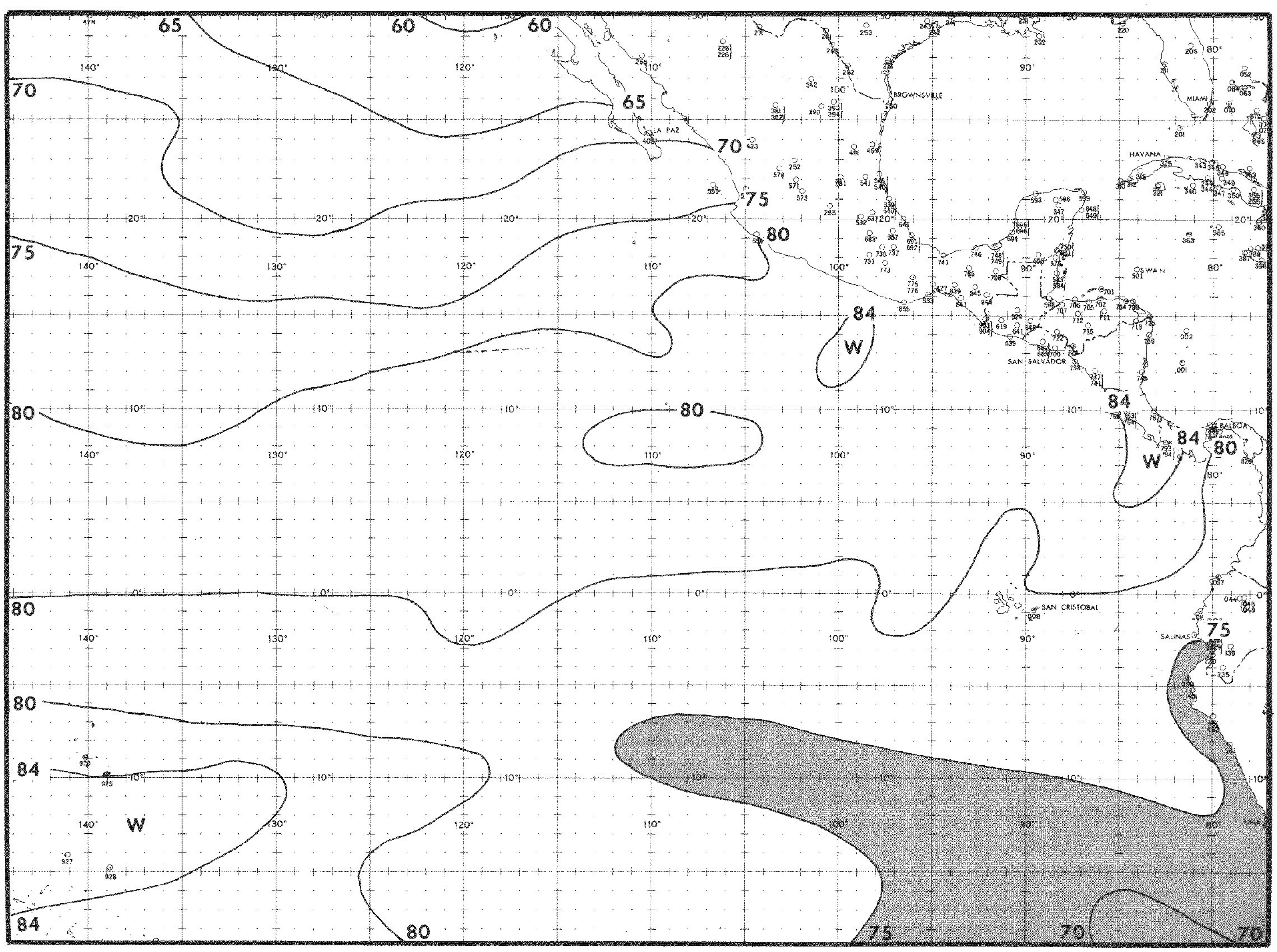


FIGURE 6.—Mean sea temperature (°F.) for February 1964, showing the cold Southern Equatorial Current.

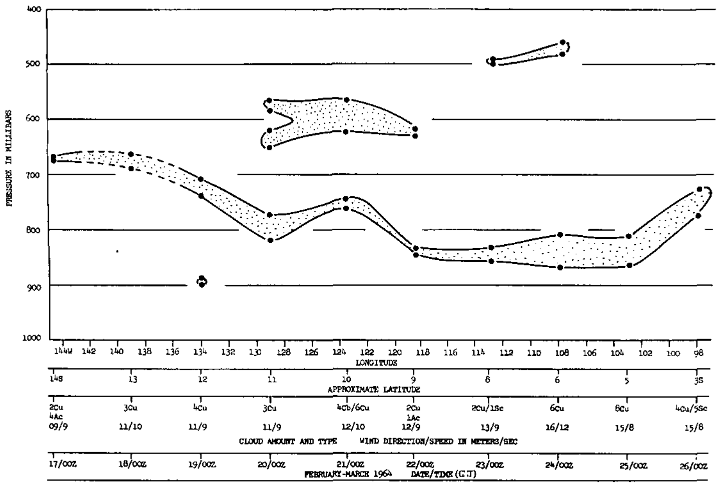


FIGURE 7.—Inversions occurring during the cruise of the *Golden Bear*, Tahiti to Ecuador leg, February 17–March 1, 1964.

### CRUISE OF THE *GOLDEN BEAR*, TAHITI TO ECUADOR, FEBRUARY 16–MARCH 1, 1964

During the cruise from Tahiti to Ecuador (fig. 7), the lower inversion sloped downward from Tahiti eastward to 9°S., 118°W., where it remained relatively sharp and low to beyond 5°S., 103°W., where it abruptly rose to 3°S., 98°W. Beyond this point it was not continuous. The region of lowest height of the inversion again corresponded perfectly with the location of the cold tongue of the Southern Equatorial Current. The upper inversion occurred in only two soundings; an inversion at 600 mb. was not considered to be the upper inversion.

### *USS PINE ISLAND* AND DARWIN RESEARCH STATION, JANUARY 19–FEBRUARY 24, 1964

The *USS Pine Island*, while stationed within 40 mi. of the Galapagos Islands from January 20 through February 8, took radiosonde observations during most of the period. Darwin Research Station took radiosonde observations from January 25 until February 24, 1964. A comparison of the soundings of the two stations taken at the same time showed the difference in the temperature lines was mostly systematic and within the absolute error of 1°C. The soundings of the ship were usually warmer. It was decided to combine the two soundings to have a longer period of observations (fig. 8).

Allowing for interruptions, the heights of the lower and upper inversions varied relatively slowly. The upper inversion was more persistent than the lower.

### ALBROOK AFB, JANUARY 19–FEBRUARY 29, 1964

The characteristics of the lower and upper inversions for Albrook AFB were obtained from the analyzed Skew-T diagrams borrowed from the station. Both inversions were found to be persistent over the station.

### CANTON ISLAND, JANUARY 19–MARCH 9, 1964

The soundings for Canton Island were analyzed to see whether this station, comparable to the Galapagos Islands in closeness to the Equator, experienced a similar inversion domain. The infrequency or absence of inversions over Canton indicated that the inversions were primarily associated with divergence over the eastern ocean and not solely an equatorial phenomenon; they rarely extended as far west as 170°W.

## 5. SUMMARY FOR THE LOWER INVERSION

The summary in table 1 shows that the lower inversion was very prevalent, except in regions of convergence found in the ITC and near Tahiti where it was missing because of the presence of a tropical cyclone. The average persistence or continuity (in time and space) of the inversion was 80 percent. The pressure of the base of the inversion ranged from 958 to 771 mb. The lowest inversion base was encountered by the *Golden Bear* near the coast of Mexico and Central America where the divergence aloft apparently was the main factor in the low height. The average height of the inversion at Darwin Research Station and Albrook AFB was very close. The average increase in temperature in the inversion layer was 2.1°C. with the greatest increase observed by the *Golden Bear* over the cold Southern Equatorial Current between South America and Tahiti. The average relative humidity of the top of the inversion was very close to the value Neiburger et al. [3] found over the North Pacific Ocean. An interesting feature is that the relative humidity of the top of the inversion at Darwin Research Station was twice that of Albrook AFB. This could possibly mean that at the level of the inversion over Darwin Research Station other factors such as the distance from the maximum divergence region and the available moisture from the warm water surrounding the station offset the effect of subsidence in creating the expected dryness at the top of the inversion. The average potential temperature $\bar{\theta}$ (°A.) of the bases and tops of the inversion, except those close to the Mexican and Central American coast, was very nearly constant. The constancy of potential temperature is thus a reliable aid in identifying the inversion.

TABLE 1.—*Summary for the lower level inversion. The bars over the quantities denote average values*

| Cruise leg or station | Period of observations | No. of obs. | Percent continuity or persistence | $\overline{\text{Press}}$ (mb.) base | $\overline{\Delta T}$(°C.) | $\overline{RH}_{top}$ (%) | $\overline{RH}_{base}$ (%) | $\bar{\theta}_{top}$(°A.) | $\bar{\theta}_{base}$(°A.) | $\bar{\theta}_{top}-\bar{\theta}_{base}$ (°C.) |
|---|---|---|---|---|---|---|---|---|---|---|
| San Diego-Peru (1st level) | 12/12–15/12 GMT Jan. 1964 | 7 | 85 | 877 | 2.0 | 28 | 44 | 300 | 295 | 5 |
| San Diego-Peru (2d level) | 16/12–25/00 GMT Jan. 1964 | 11 | 91 | 807 | 1.0 | 61 | 82 | 310 | 306 | 4 |
| Ecuador-San Diego | 7/12–17/12 GMT Mar. 1964 | 19 | 68 | 958 | 0.9 | 46 | 81 | 300 | 296 | 4 |
| Peru-Tahiti | 31/00–11/00 GMT Jan.–Feb. 1964 | 12 | 75 | 771 | 4.6 | 18 | 62 | 312 | 303 | 9 |
| Tahiti-Ecuador | 17/00–1/12 GMT Feb.–Mar. 1964 | 14 | 79 | 786 | 2.5 | 31 | 68 | 311 | 304 | 7 |
| *USS Pine Island* and Darwin Research Station | 19/00–24/12 GMT Jan.–Feb. 1964 | 48 | 77 | 788 | 1.5 | 57 | 78 | 309 | 304 | 5 |
| Albrook AFB | 19/00–9/00 GMT Jan.–Mar. 1964 | 101 | 89 | 791 | 1.9 | 23 | 67 | 313 | 306 | 7 |
| Average | | | 80 | 816 | 2.1 | 39 | 73 | 309 | 303 | 7 |

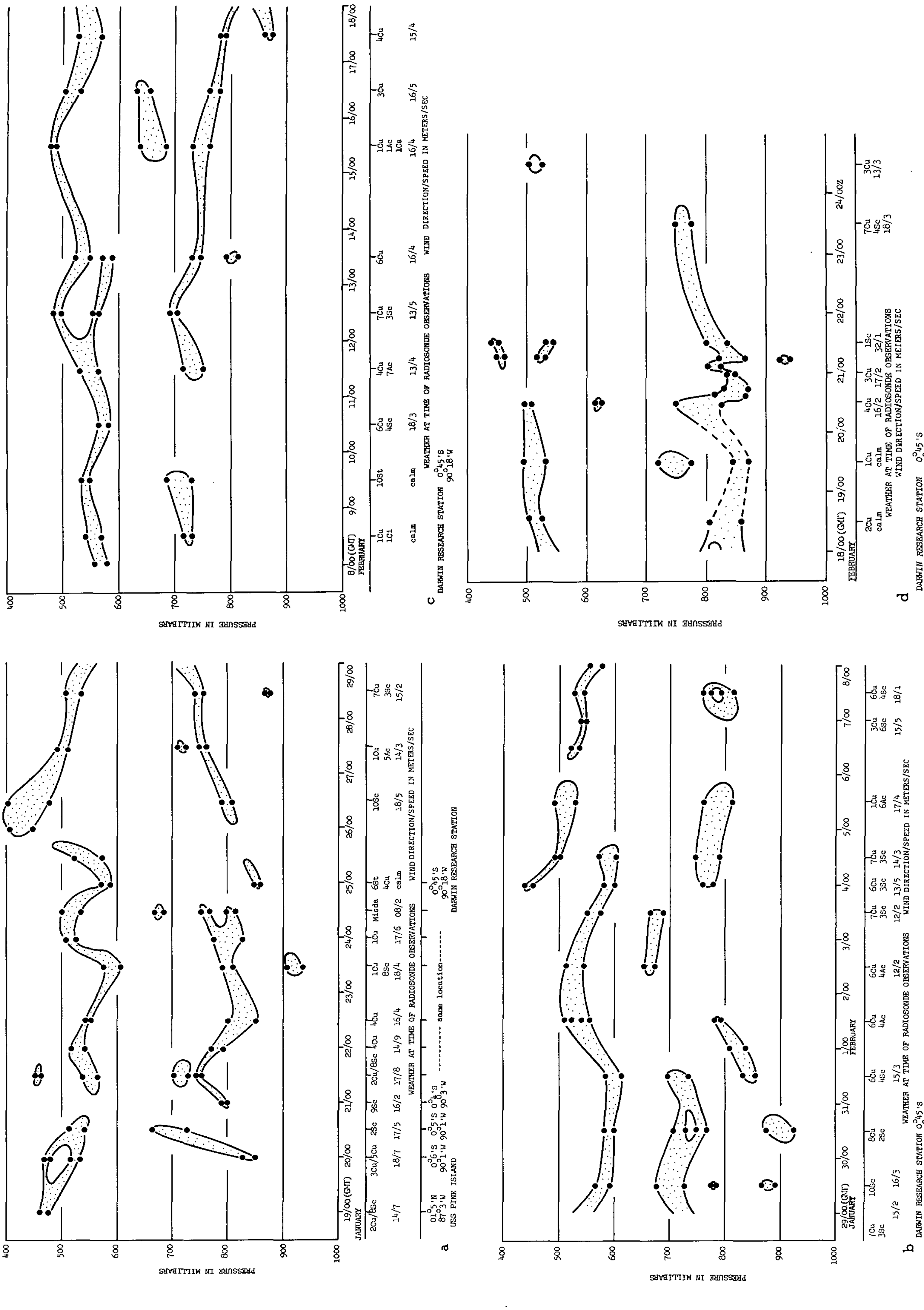


FIGURE 8.—Inversions occurring in soundings taken by *USS Pine Island* and at Darwin Research Station, (a) January 19–29, (b) January 29 February 8, (c) February 8–18, and (d) February 18–24, 1964.

TABLE 2.—*Summary for upper level inversion. The bars over the quantities denote average values.*

| Cruise leg or station | Period of observations | No. of obs. | Percent continuity or persistence | $\overline{\text{Press}}$ (mb.) base | $\overline{\Delta T}$(°C.) | $\overline{\text{RH}}_{top}$(%) | $\overline{\text{RH}}_{base}$(%) | $\bar{\theta}_{top}$(°A.) | $\bar{\theta}_{base}$(°A.) | $\bar{\theta}_{top}-\bar{\theta}_{base}$(°C.) |
|---|---|---|---|---|---|---|---|---|---|---|
| San Diego-Peru | 12/12–25/00 GMT Jan. 1964 | 19 | 58 | 497 | 1.5 | 26 | 52 | 330 | 325 | 5 |
| Eduador-San Diego | 7/12–17/12 GMT Mar. 1964 | 19 | 79 | 626 | 1.5 | 27 | 51 | 319 | 313 | 6 |
| Peru-Tahiti | 31/00–11/00 GMT Jan.–Feb. 1964 | 12 | 0 | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Tahiti-Ecuador | 17/00–1/12 GMT Feb.–Mar. 1964 | 14 | 14 | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| *USS Pine Island* and Darwin Research Station. | 19/00–24/12 GMT Jan.–Feb. 1964 | 48 | 90 | 544 | 1.3 | 19 | 45 | 327 | 320 | 7 |
| Albrook AFB | 19/00–9/00 GMT Jan.–Mar. 1964 | 101 | 80 | 543 | 1.5 | 11 | 36 | 326 | 322 | 4 |
| Average | ---- | ---- | 77 | 550 | 1.5 | 22 | 45 | 326 | 320 | 5 |

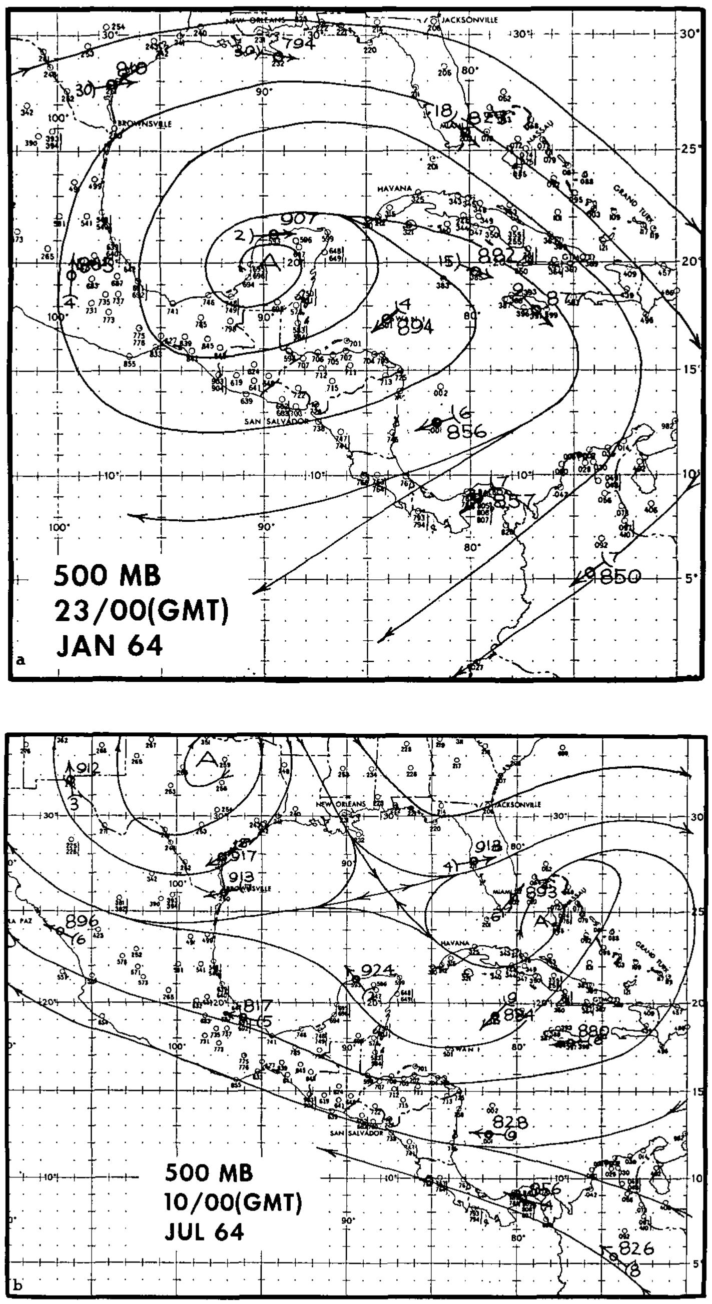


FIGURE 9.—Typical (a) winter and (b) summer 500-mb. wind flow over Central America.

## 6. SUMMARY FOR THE UPPER INVERSION

The summary in table 2 shows that the average continuity or persistence of the upper inversion, except in the soundings taken between Tahiti and South America, was very high. This suggests that the upper inversion is of equal importance with the lower inversion. The average increase in temperature through the inversion was 1.5° C., slightly less than that of the lower inversion. Similar characteristics of the inversion over Darwin Research Station and over Albrook AFB suggest that over both stations it originates from the same source and its effect on the weather should be similar for both stations. If the inversion over the two stations is assumed to be the same one, investigation of the cause of the inversion is easier because the lack of data over the ocean can be offset by studying the area surrounding Albrook AFB where upper level data are available.

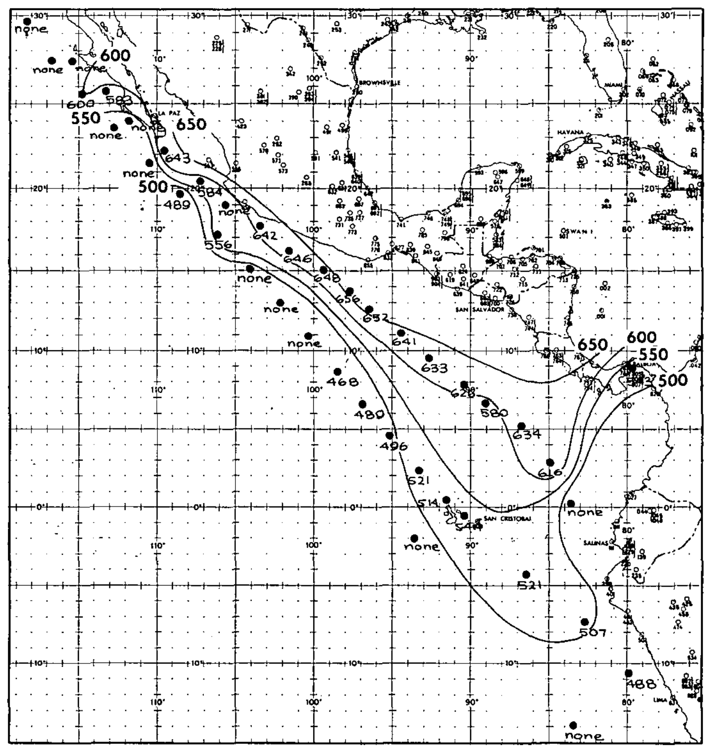

FIGURE 10.—Pressure analysis (mb.) of the base of the upper inversion during the Galapagos expedition.

## 7. CAUSE OF THE UPPER INVERSION

When this study was first started, it was thought that the inversion was caused by, and directly related to, the downslope winds over the Andes Mountain at this level. The 500-mb. wind blew from the ENE over the Andes and at Albrook AFB, and this simple explanation seemed adequate to explain the persistent occurrence of the inversion. But inspection of the soundings of Albrook AFB from July 1–20, 1964, showed no inversion at this level even though the wind at 500 mb. was still easterly over the Andes and Albrook AFB. This eliminated the hypothesis

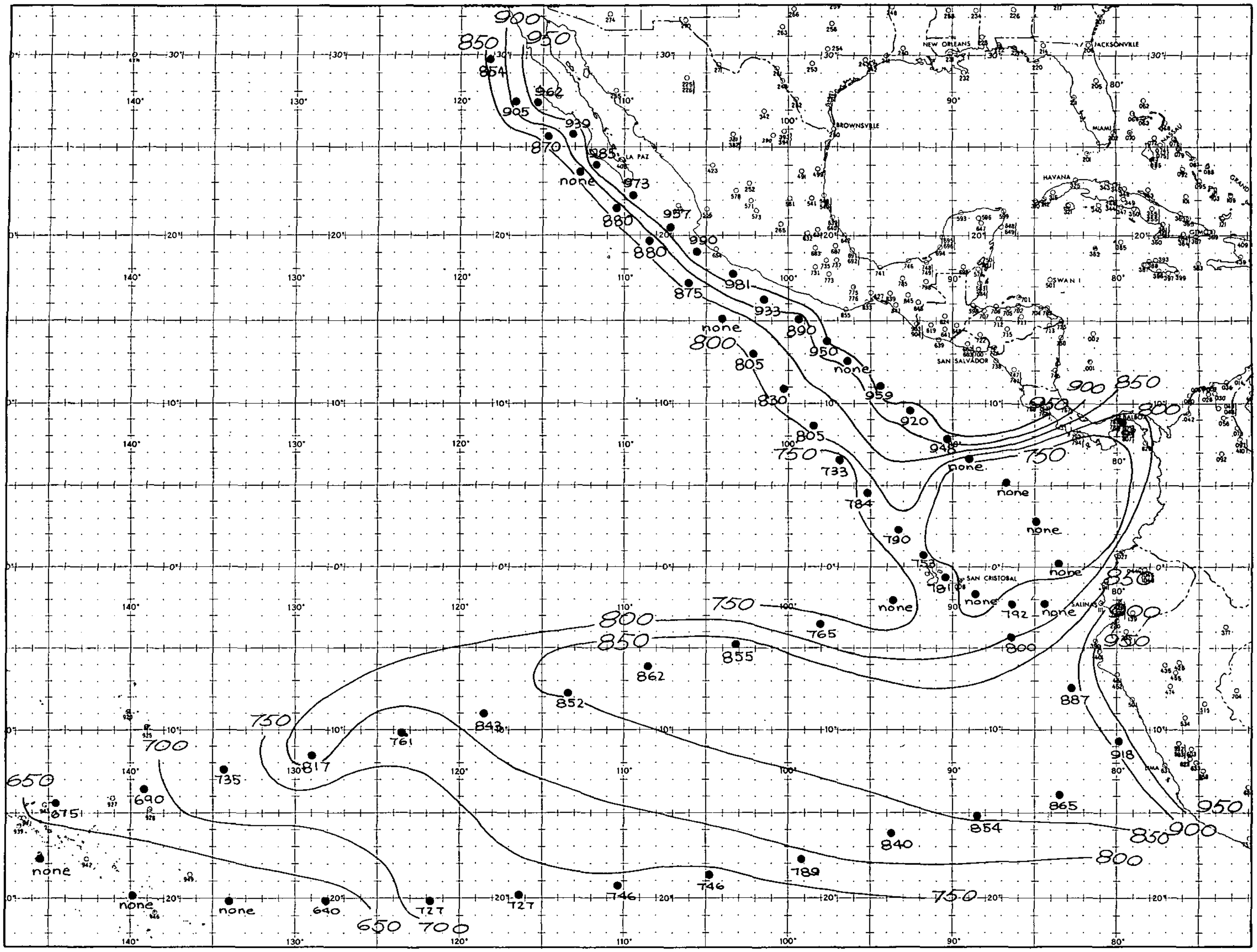


FIGURE 11.—Pressure analysis (mb.) of base of lower inversion during the Galapagos expedition.

that flow down the Andes always causes an inversion. The lower inversion was also missing during this period. The 500-mb. streamlines over Central America and the Caribbean Sea were analyzed for the summer and winter months of 1964. Figure 9, the analyses for 2 typical days of the opposite seasons, shows that during winter there was a persistent anticyclonic circulation over this area with the center over Central America. On the other hand, during summer, the High had migrated northward and zonal easterly flow was present from 15°N. latitude southward. This suggests that the upper inversion is caused by, and related to, the "dynamic" anticyclone of winter. Figure 10 shows the analysis of the pressure of the base of the upper inversion. The area covered by the inversion extended from Central America westward to a line drawn from 23°N., 110°W., diagonally to 10°S., 80°W. The inversion sloped upward toward the west and south. The 500-mb. anticyclonic circulation of winter was perfectly superimposed over the area of the inversion with the lowest height closest to the center of the High. Petterssen et al. [4] found statistically that 80 percent of the investigated cases of subsidence inversions within the British Isles were associated with anticyclonic vorticity. This is in accord with the present study's finding that the upper inversion is related to the anticyclonic circulation around the High located in the vicinity of Central America during winter. They also found that the tops of the inversions were most frequent between 700 and 500 mb.

## 8. EFFECT OF THE LOWER INVERSION ON THE WEATHER DURING THE GALAPAGOS EXPEDITION

Figure 11 shows the analysis of all the pressures of the base of the lower inversion observed during the cruise of the *Golden Bear*. The inversion was lowest off the Mexican and Central American coast and sloped rapidly upward toward the west and south. In the vicinity of the ITC

(5°N. latitude) the inversion was either missing or high. On the south side of the ITC the inversion was missing or high which points out the greater instability of the southern side of the ITC. In the Southern Hemisphere, the westward upslope of the inversion from South America was not readily seen because the zone of low heights of the inversion over the cold Southern Equatorial Current extended westward from Peru to 6°S., 115°W. The gradual sloping outward (towards north and south) from this zone dominated the area.

The lower inversion has a pronounced effect on the weather of this region. Near the Mexican coast, where the pressure of the base was higher than 925 mb., fair weather cumulus and stratocumulus low clouds predominated. No precipitation was observed until 15°N., southward of which the inversion was higher. In the region of the cold tongue of the Southern Equatorial Current where the inversion was lower again, cumulus and stratocumulus low clouds were the dominant clouds and no precipitation occurred. In the other areas of the tropical Eastern Pacific, where the base of the inversion was above the 800-mb. level, showers occurred. The area of greatest probability of precipitation occurring was in and south of the ITC where the inversion was the highest, caused mainly by convergence from below. Over Darwin Research Station, the average height of the inversion was 788 mb. and 12 out of 63 observations reported light showers.

## 9. EFFECT OF THE UPPER INVERSION ON THE WEATHER DURING THE GALAPAGOS EXPEDITION

The influence of the upper inversion on the weather was not as extensive in area as the lower inversion but possibly just as important for the control of severe weather. There was no cumulonimbus buildup observed in the area of the upper inversion. On the other hand, in the case of the Northern Hemisphere summer, when this inversion was not present, cumulonimbus clouds were reported in the surface observations. This suggests that the inversion, or the synoptic pattern responsible for the inversion, may be a factor in inhibiting the growth of a low level vortex during winter, even if the sea surface waters are warm, by acting as a "lid" on cloud development beyond its base.


## ACKNOWLEDGMENTS

The author is grateful to Dr. C. E. Palmer for furnishing the Galapagos Expedition data and for his comments; Dr. Morris Neiburger and Dr. T. N. Krisnamurti for their comments; Alameda Weather Central, Howard Weather Central, and Honolulu Weather Bureau for the use of their data; and ETAC, USAF for furnishing the ships' logs.


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[*Received June 30, 1967; revised October 17, 1967*]